

DEVELOPMENT OF AN EARLY WARNING FIRE DETECTION SYSTEM USING CORRELATION SPECTROSCOPY

K. Goswami, G. Voevodkin, V. Rubstov, and R. Lieberman
Intelligent Optical Systems
2520 West 237th Street
Torrance, CA 90505, USA

N. Piltch
NASA - Glenn Research Center
21000 Brookpark Road, MS 110-3
Cleveland, OH 44135

INTRODUCTION

Combustion byproducts are numerous. A few examples of the gaseous byproducts include carbon dioxide, carbon monoxide, hydrogen chloride, hydrogen cyanide and ammonia. For detecting these chemical species, classic absorption spectroscopy has been used for many decades, but the sensitivity of steady-state methods is often unsuitable for the detection of trace compounds at the low levels (parts per million to parts per billion) appropriate for scientific purposes. This is particularly so for monitoring equipment, which must be compact and cost-effective, and which is often subjected to shock, vibration, and other environmental effects that can severely degrade the performance of high-sensitivity spectrometers in an aircraft. Steady-state techniques also suffer from a lack of specificity; the deconvolution of the spectra of complex mixtures is a laborious and error prone process. These problems are exacerbated in remote fiber-optic monitoring where, for practical reasons, the fundamental absorbance region of the spectrum (often between 3 and 8 μm) is inaccessible, and the low-strength, closely spaced, near-infrared overtone absorbance bands must be used. *We circumvented these challenges by employing correlation spectroscopy, a variation of modulation spectroscopy.*

In correlation spectroscopy, a dramatic increase in sensitivity is achieved by phase- or wavelength-modulation of a very narrow band optical source whose natural wavelength coincides with one of the absorbance lines of the target compound. Highly specific chemical detection is accomplished by using a sample of the target compound itself as an optical filter. The positions of the absorbance maxima in the filter sample are modulated via an external physical process, such as an electric field (Stark effect modulation) or pressure. This modulation, which brings the reference sample's absorbance bands periodically into and out of registry with the absorbance bands of the target gas in the substance under test, creates a modulated signal at the detector whose intensity is directly related to the concentration of the target. This technique can achieve one or two orders of magnitude better sensitivity than simple modulation of the source intensity, and has the added benefit of rendering the detection system virtually insensitive to other gases. Because the detailed structure (e.g., the manifold of rotational states on infrared vibrational absorbance bands) is unique for each compound, the use of tunable fiber

Bragg grating (FBG) filters matched to the spectral properties of the target compound makes correlation-spectroscopy systems extremely good at detecting trace quantities of target molecules in complex mixtures.

EXPERIMENTAL SETUP AND RESULTS

Currently, we are developing a prototype instrument, which will use the correlation spectroscopic approach for detecting trace gases. We have targeted the detection of carbon monoxide in the near infrared (NIR) region. Figure 1 shows the NIR spectrum of carbon monoxide.

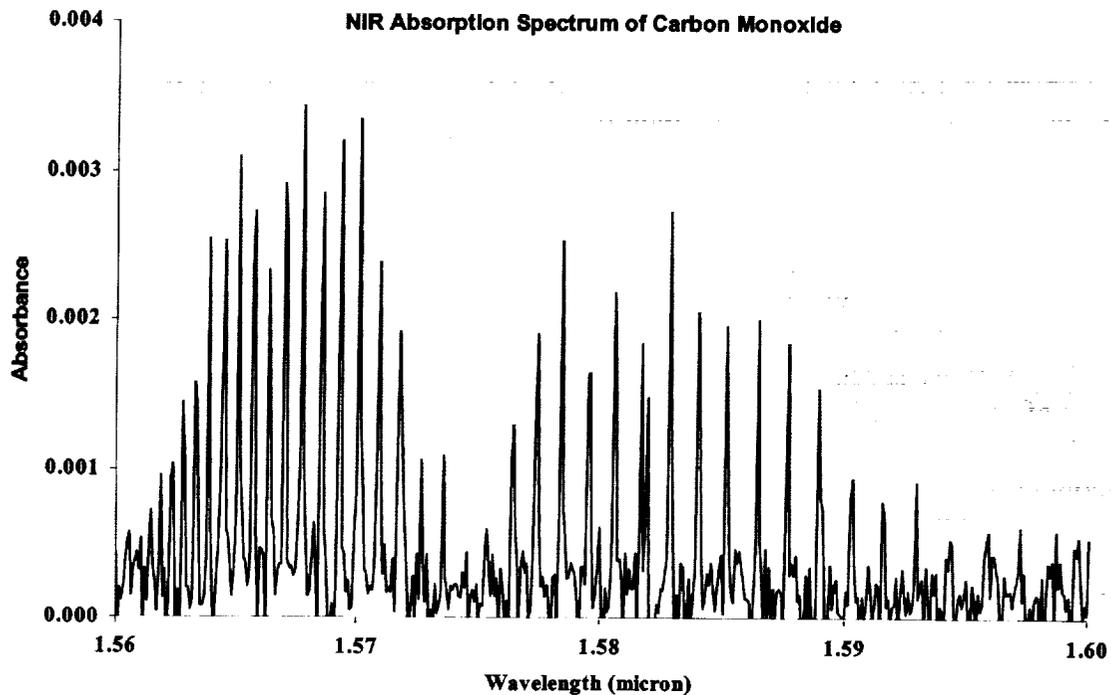


Figure 1
Absorption spectra of 100% CO acquired with FT-NIR (15 cm pathlength)

Figure 2 shows the schematic diagram of the experimental arrangement.

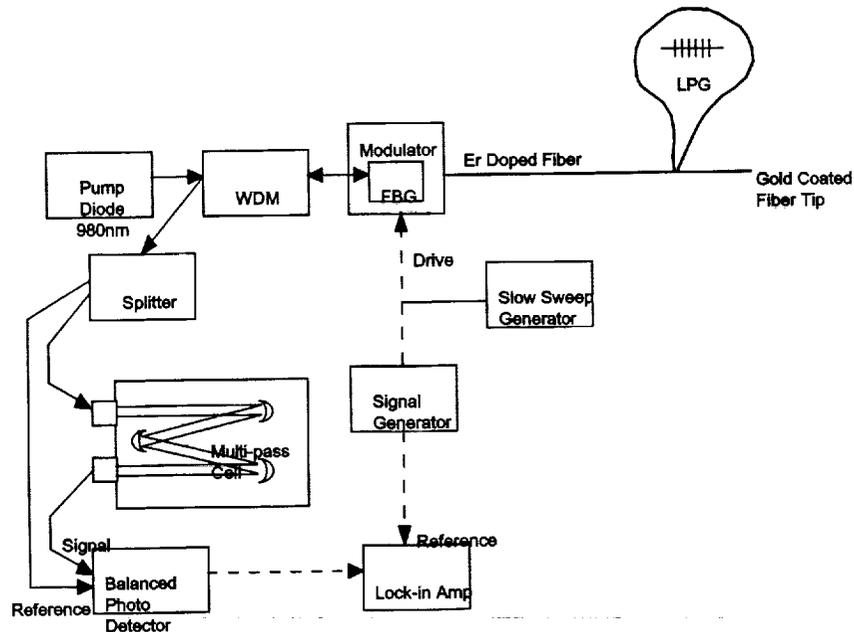


Figure 2

Schematic diagram of the experimental setup showing the Erbium fiber-doped fiber laser as the light source.

Spectroscopic detection of carbon monoxide requires a light source. Because commercially available light emitting diodes do not have sufficient power, we are utilizing Erbium-doped fiber laser (EDFL) in the L-band (power 10 mW). As Figure 2 shows, the output of the EDFL is coupled to a splitter. One fraction of the laser power directly goes to a reference photodiode, and the other fraction (the signal) passes through a multipass cell. We have utilized a GRIN (GRAded INdex) lens for collimating the signal beam before entering into the multipass cell. After traversing through the multipass cell, the modified signal beam is detected by another photodetector. The reference and signal beams are converted to electrical parameters. By using a processing chip we are able eliminate the common mode noise of the EDFL.

As can be seen from Figure 1, the absorption lines of carbon monoxide span nicely over the 1560 – 1590 nm range. We designed our EDFL to yield output in this region. We achieve this control of wavelength selection by utilizing fiber Bragg grating (FBG). The laser cavity consists of the FBG on one side of an Er^{3+} -doped fiber, and a gold coated mirror on the other.

The Bragg wavelength is dependent on strain and temperature. Thus, by varying either strain or temperature, we can tune the EDFL for a match with any absorption line of carbon monoxide. The strain-induced shift in wavelength is typically 1.2 nm/me, and temperature-induced shift is about 0.1 nm per degree C. The FBG will break if the strain exceeds 1%. This implies a theoretical tuning range of 12 nm where the lower wavelengths are accessed by compressing the grating. Experimentally, we produced 1584

nm gratings that could be tuned from 1584 to 1590 nm using a compact fiber-holding device. This pencil-like device is shown in Figure 3.



Figure 3

A PZT driven fiber stretcher

To apply strain to the Bragg grating in a controllable manner, we attached the grating to a PZT actuator. When connected to a function generator, the PZT stack vibrates at a set frequency. The resonance of the modulator was kept around 3000 Hz. Following the manufacturer's instructions, we did not operate the device at resonance or above resonance frequencies. We demonstrated 0.5 nm tuning at a modulation frequency around 3 kHz.

CONCLUSION

This is an ongoing project. During the actual presentation, we will show data on the performance of the system with respect to detecting low concentrations of carbon monoxide.

ACKNOWLEDGEMENT

Intelligent Optical Systems gratefully acknowledges funding support for this project from NASA-GRC through a Phase II SBIR contract (NAS3-00016).